



CONFOEDERATIO, RESEARCH DIVISION (CRD).

ERROR CORRECTION:

How to Calculate the GDP Per Capita of the Western Sahara, ~10000BC-2025AD.

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Abstract.

This is part of a series of papers intended to fill out missing data in the Maddison Project Database using other known and primary sources. We provide a case study of the demography and economy of the Western Sahara, for which few if any records currently exist through the integration of backcalculation, primary sources, and OLS proxy modelling on a HYDE3.3-extended SEDAC database.

Calculating the Modern GDP Per Capita of the Western Sahara, 1970-2025AD.

We must first start by attempting an estimate of their modern GDP per capita by assessing the sorts of data available to us as historical demographers. We can find a well-meaning dataset of CO2 emissions from the Western Sahara sorted by year and sector in tons as provided by the Emission Database for Global Atmospheric Research (EDGAR), IEA, and World Population Prospects: The 2024 Revision provided by Worldometer [1]. For middle-income and lower-income countries like the Western Sahara, CO2 emissions are a good proxy of economic growth.

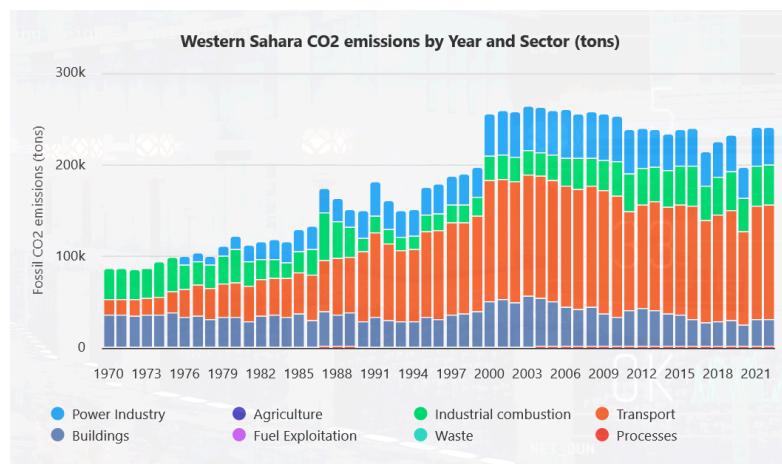


Figure 1. CO2 emissions growth in the Western Sahara, 1970-2022AD.

Unfortunately, the UN website was down for maintenance at the time of this paper, and the IEA did not appear to provide the given data claimed by Worldometer, meaning that it almost certainly falls to EDGAR given that it has the exact same timeframe (1970-2023AD), and is described as '[providing] both emissions as national totals and gridmaps at 0,1x0,1 degree resolution at global level, with yearly, monthly, and up to hourly data' [2].

An additional EU report with the Western Sahara from 2023AD has virtually no data apart from import/export ledgers for which we note that imports for the EU27 grew by 19,4bn Euro and exports (to the Western Sahara) grew 18,7bn Euro [3]. More detailed figures in a secondary taxation and customs report indicates more solid economic figures by which GDP growth composition is stated as follows:

'In terms of income growth, the 2019 regional accounts show GDP growth rates of 6,7% for Laayoune-Sakia El Hamra, and 4,1% for Dakhla-Oued Ed-Dahab. By comparison, Morocco's growth rate is weaker, at 2,9%. However, this difference can be explained by significant investments by the Moroccan authorities, which make up 35% of the GDP of these two regions, compared to 20% for Morocco on average' [4]. Given that some two-thirds of the population are presently Moroccan settlers, we can sort of take the Moroccan view on GDP per capita for 2023-2025AD [5].

The imputed growth ratio to the rest of Morocco can then be calculated for the study year by taking the population weighted average of both provinces' GDP growth:

$\frac{1,067(367758) + 1,041(142955)}{367758 + 142955}$, which comes out to a scalar of $\frac{5,9722273\%}{2,9\%} = 2,059388724$.

Given the greater role of the Moroccan state in Western Saharan GDP, we can use this scalar on official World Bank accounts for Moroccan real GDP growth adjusted to inflation [6]:

Year	Real GDP Growth	Implied Western Saharan Real GDP Growth
2019	2,9%	5,9722273%
2020	-7,2%	-14,82759881%
2021	8,2%	16,88698754%
2022	1,5%	3,089083086%
2023	3,4%	7,001921662%

2024	2,9%	5,9722273%
2025	4,0%	8,237554896%

With that complete, we now need a reference year to compare GDP per capita to.

According to Moody's Analytics, the only available reference year is 2007, where the GDP per capita reached a rough \$2500 PPP per capita [7]. We first take the international dollar PPP deflator difference in scalars as provided by the IMF for Morocco: 4,09 for 2007 and

4,05 for 2011; such that $GDP_{PPP} \frac{4,05}{4,09} (\frac{CPI_{US}(2007)}{CPI_{US}(2011)})$ is our conversion factor to 2011\$, or

\$3.218,22 for the Western Sahara in 2007 as a benchmark year. Since this is outside of our contemporary data range, we now turn to CO2 growth statistics adjusted for population to give us the answer as to 2011\$ GDP PPP per capita for the Western Sahara, for which we realise that the Western Sahara when accounting for population has actually been in a bit of a per capita funk.

Year	CO2 Emissions (tons)	CO2 Emissions per Capita	Population	Est. GDP (PPP) per capita growth	Est. GDP (PPP) per capita (2011\$)
2022	241.500	0,4246235971	568.739	0,9837949865	1957,77464
2021	241.110	0,4316179722	558.619	1,19973592	1990,022989
2020	197.640	0,3597608148	549.365	0,8313360504	1658,717519
2019	233.010	0,4327501671	538.440	1,008028745	1995,243101
2018	225.720	0,4293033995	525.782	1,0250733	1979,351393
2017	214.780	0,4188026355	512.843	0,8717511899	1930,936445
2016	240.040	0,4804153299	499.651	0,9811757153	2215,008671
2015	238.070	0,4896323079	486.222	0,9911756112	2257,50458
2014	233.450	0,4939914808	472.579	0,9490678277	2277,603035
2013	238.090	0,5205017664	457.424	0,9585260952	2399,831675
2012	239.490	0,5430230528	441.031	0,9662287168	2503,668588
2011	238.900	0,5620026018	425.087	0,910304242	2591,175924
2010	252.950	0,6173788673	409.716	0,9540205223	2846,494396
2009	255.590	0,6471337386	394.957	0,9570221141	2983,682562
2008	257.510	0,6761951778	380.822	0,9687571333	3117,673582
2007	256.070	0,6980027858	366.861	0,9466525206	3218,22

2006	260.020	0,7373379045	352.647	0,962149834	3344,822071
2005	259.560	0,7663441581	338.699	0,9466929675	3533,16459
2004	263.240	0,809495987	325.190	0,9554718789	3697,82164
2003	264.150	0,8472211531	311.784	0,9791860836	3776,42381
2002	258.240	0,8652299775	298.464	0,9532303439	3961,711704
2001	258.860	0,9076819502	285.188	0,9667401111	4098,011097
2000	255.330	0,9389099922	271.943	1,229140541	3334,045995
1999	197.820	0,7638752129	258.969	0,9886265589	3372,401808
1998	190.310	0,7726630505	246.304	0,962219046	3504,817144
1997	187.720	0,803001202	233.773	0,9928736504	3529,972965
1996	179.050	0,8087647423	221.387	0,9665212898	3652,245432
1995	175.660	0,8367790248	209.924	1,118945345	3264,006993
1994	151.000	0,7478283264	201.918	0,9809642315	3327,345573
1993	149.780	0,7623400552	196.474	0,9077623041	3665,43704
1992	160.350	0,8398014015	190.938	0,8593726513	4265,247486
1991	181.080	0,9772261198	185.300	1,172044666	3639,150973
1990	149.700	0,8337789066	179.544	0,9606712737	3788,133436
1989	150.950	0,867912812	173.923	0,8956643228	4229,412002
1988	163.190	0,9690157237	168.408	0,9026154812	4685,729515
1987	174.860	1,073564263	162.878	1,26461836	3705,251849
1986	133.590	0,8489235149	157.364	0,9968479776	3716,967815
1985	129.240	0,8516078018	151.760	1,078437572	3446,623069
1984	115.410	0,7896681492	146.150	0,9367539202	3679,326016
1983	118.510	0,8429835543	140.584	0,9807532777	3751,530685
1982	115.590	0,8595266246	134.481	0,9701191012	3867,082588
1981	112.430	0,8860011348	126.896	0,8492037987	4553,774481
1980	122.460	1,043331573	117.374	0,9831253193	4631,936938
1979	111.410	1,061239653	104.981	0,9590090802	4829,919793
1978	100.580	1,106600213	90.891	0,8282965211	5831,14823
1977	103.390	1,335995245	77.388	0,8627778624	6758,574233
1976	99.860	1,548481136	64489	1,041701244	6488,015897
1975	99.430	1,486492547	66889	1,205668581	5381,259823
1974	94.290	1,232919701	76477	1,087717875	4947,293728

1973	88.010	1,133492176	77645	1,035547335	4777,467489
1972	85.650	1,094582678	78249	0,9867885998	4841,429552
1971	86.820	1,109237256	78270	0,9757378306	4961,813922
1970	86.820	1,13681895	76371		4961,813922

Table 2. Estimated CO2-emissions based GDP per capita for the Western Sahara, 1972-2022AD.

With this out of the way, we assume population growth in the region for the past 3 years has been not statistically significant for the past 3 years to bring it up to 2025.

The Hungarian Element, 1899-1900AD.

I have searched the original Gran Atlas Aguilar through and through in my personal library and have come to the conclusion that Spanish administrators were great fiends for documenting Equatorial Guinea, but simply put question marks all over the Rio de Oro [8].

But would you believe it! Through a fortuitous historical quirk, the Spanish did appraise the worth of their colony to a Hungarian delegation around 1899-1900AD, providing some real grounding for our estimates apart from just Maddison and Gapminder's appraisals of neighbouring Mauritania, a relative peer economy:

'According to the calculations, the acquisition of the area by the Monarchy, the purchase of the infrastructure developed by the Spanish, would have cost approximately HUF 150.000 and the development and operation of the commercial site would have cost another HUF 100.000 ... Therefore, the area [Rio de Oro] did not pay the rent of HUF20.000 in 1899, not even the deposit of HUF50.000 negotiated by the end of 1899, which was a basic condition for the continuation of the negotiations' [9].

Fun! A Hungarian Florin in 1899AD is believed to have been worth \$74,72292310588728 in FY2000 International Dollars, adjusted to Swedish wage prices [10]. The decimal precision of our Hungarian diplomatic excerpt should say, however, that a further conversion to US prices is not really needed. Given that the demanded rent was HUF20.000, it implies the Spanish believed the Rio de Oro to be worth at least that much in terms of taxable income/economic productivity.

We can combine this with the date of its historical founding in 1884 (15 years at time of cable) to ascertain that the Spanish spent at least HUF10.000 per year, which we can lump onto the GDP. Exports are believed to have been minimal at this time, and the Spanish appraisal is likely somewhat overstated, though this balances out native economic productivity, coming out to a GDP of HUF30.000/year, with the population in 1900 believed to be 24.000, or a Spanish-controlled GDP of \$2.241.687 [11]. This would put its GDP per capita at a shockingly low \$93,40365388 FY2000 International Dollars. Clearly, this cannot be right.

The better explanation is that this rent and infrastructure was generally restricted to Spanish postings. So how many Spanish were there in the Western Sahara at the time? In the 1920s-1930s, this number was generally estimated at 703, which would put estimated GDP per capita for Spanish postings at \$3.188,74; a relatively high sum [12]. Now, this would be about the end of it, if a Spanish expedition did not tell us a certain Mr. Ayoub, a Reguibat merchant, had haggled and traded about for a year in effect to gain 779 francs, or \$33.678,21 (in the form of ostrich feathers) as of 7 April 1893 [13].

We can use the Gini coefficients of the Juhaina Arabs, a pastoralist society of the Sahel, to ascertain a Gini coefficient of 0,535 +/- 0,226 [14]. We can ironically assume that the Spaniards in our sample, based on their language, were ordinally positioned a decile below Mr. Ayoub on the GDP per capita scale given their reaction that he was fantastically wealthy and that *'the fabulous profits that this article alone leaves the trader, should in general make them more humane towards us'*. We then conclude the 99th percentile is \$33.678,21 and the 90th percentile is \$3.188,74, with a peer Gini coefficient of 0,535.

We can then use a Pareto-tail toy model to generate what we believe to be the estimate of Western Saharan GNI in 1900, where:

population = 24.000, $P_{50} = \$849$, $P_{90} = \$3.188,74$; $P_{99} = \$33.678,21$; *Gini* = 0,535;
log-normal parameters (<P90): $\mu = 6,744$; $\alpha = 1,032$; *population* = 2.400;
Pareto tail ($\geq P_{90}$): $\alpha = \sim 0,978$; *population* = 21.600.

For $\geq P_{90}$, the Pareto mean formula would be $Mean_{LN} = \frac{\alpha x_m}{\alpha - 1}$, for $\alpha > 1$, but our $\alpha = 0,978$, so we resort to a heavy-tailed simple estimate as follows: $\bar{x}_{D10} = \sim 2,5 P_{90} = 2,5(3.188,74)$, which is $\sim \$7.971,85$; where total income for $\geq P_{90}$ is: $2.400(7.971,85) = \$19.132.440$.

For <P90, we use a log-normal CDF approximation, such that

$$Mean_{LN} = e^{\mu + \frac{1}{2}\sigma^2} = e^{6,744 + 0,5(1,032)^2} = \sim \$1.443,76; \text{ where total income for } <P90 \text{ is:}$$

21.600(1.443,76) = ~31.729.216; giving a total GNI of I\$31.729.216, to which we add our preceding 'settler GDP' of I\$2.241.687, rendering a total toy GDP of \$33.970.903; or I\$1.415,45 in GDP (PPP) per capita. This is in-line with most pre-industrial estimates; and a quick conversion of our FY2000 International Dollars back up FY2011 International Dollars gives us \$1.846,85 (or \$44.324.400 total for 1900AD). We will use this for pre-1900 backscaling; whilst preserving our modern estimates for post-1900 backscaling.

OLS Modelling, 10000BC-2025AD.

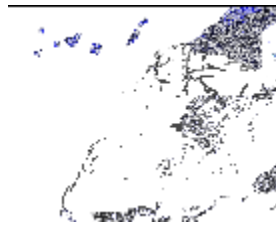


Image 1. Assumed potential economic activity per gridcell for the Western Sahara in 32bit integer RGBA encoding at 5-arcminute resolution based on OLS modelling in 1800AD.

Like a thirsty traveller east of the Moroccan sand berm, the data runs out here. Using the Eoscala database; in particular, its HYDE3.3-SEDAC trained model (SEDAC having been extended to 2015AD by Kummu et al.), and using HYDE3.2/3.3's population figures combined with McEvedy and Jones, we can calculate an estimated GDP per capita for the remaining missing years and finally fill in this great mystery [15].

We can use the growth in said potential economic activity scores from this hybrid population/land use model to fill in GDP PPP growth rates (to which the initial Kummu-extended SEDAC model was based) to resolve any pesky missing figures. Linear interpolation was used for missing data points.

Year	Potential Economic Activity	Velkskala Population	PEA Per Capita	Growth in PEA per Capita*	Est. GDP (PPP) per Capita, 2011\$
-10000	915,00	452	2,0229125	0,7596310364	236,2010231
-9000	1.281,00	834	1,536667119	1	179,4256279

-8000	11.530,00	1.215	9,490286051	0,833603666	179,4256279
-7000	12.628,00	1.596	7,911137244	0,8890636189	149,5698612
-6000	13.909,00	1.978	7,033504308	1,555370282	132,9771221
-5000	25.805,00	2.359	10,93970358	1,294353511	206,8286639
-4000	38.800,00	2.740	14,15984373	1,416744854	267,7094072
-3000	62.619,00	3.121	20,06088574	1,282199803	379,2759251
-2000	90.098,00	3.503	25,72206375	1,301184017	486,3075164
-1000	129.996,00	3.884	33,46913823	1,099314698	632,7755677
0	156.935,88	4.265	36,79311558	0,9795008822	695,6194819
100	183.875,76	5.102	36,03888917	0,8931386583	681,3598962
200	210.815,65	6.550	32,18772512	0,9651526055	608,5488635
300	237.755,53	7.653	31,06606676	0,9670016018	587,3425212
400	264.695,41	8.811	30,04093632	1,002925902	567,9611588
500	291.635,29	9.680	30,12883315	1,01859827	569,6229574
600	318.575,18	10.381	30,68917731	1,033668437	580,2169587
700	345.515,06	10.892	31,72243394	1,070413307	599,7519567
800	372.454,94	10.969	33,95611543	1,139527458	641,9824756
900	399.394,82	10.322	38,6939259	1,190579134	731,5566585
1000	426.334,71	9.254	46,06818079	1,160771474	870,976093
1100	453.274,59	8.476	53,47463014	0,9619085042	1011,004204
1200	480.214,47	9.336	51,43770149	0,9037270969	972,4935412
1300	507.154,35	10.910	46,48564464	1,275162999	878,8687648
1400	534.094,24	9.010	59,27677402	1,075270869	1120,70093
1500	561.034,12	8.802	63,73858831	1,009625512	1205,057062
1600	587.974,00	9.137	64,35210487	0,5030684078	1216,656354
1700	583.675,00	18.029	32,37351093	1,976449045	612,0613748
1710	615.294,00	9.616	63,98459478	1,014428343	1209,70812
1720	654.705,00	10.087	64,90778643	1,017280609	1227,162203

1730	696.781,00	10.553	66,02943253	1,026378486	1248,368314
1740	744.589,00	10.987	67,771189	1,029171898	1281,29838
1750	796.912,00	11.426	69,74820322	1,041499353	1318,676286
1760	856.598,00	11.792	72,64270854	1,041143306	1373,400499
1770	923.314,00	12.208	75,63146974	1,046947313	1429,906736
1780	996.388,00	12.583	79,18216403	1,04748344	1497,037015
1790	1.076.339,00	12.977	82,94200555	1,045939513	1568,121482
1800	1.157.962,00	13.348	86,75232085	1,050634905	1640,160219
1810	1.248.752,00	13.701	91,1450164	1,050683096	1723,209576
1820	1.342.797,00	14.022	95,76452798	0,9986296782	1810,547172
1830	1.493.653,00	15.619	95,63329976	1,000757103	1808,066139
1840	1.641.535,00	17.152	95,705704	0,9994959947	1809,435031
1850	1.779.164,00	18.599	95,65746782	0,9996024752	1808,523066
1860	1.912.533,00	20.002	95,6194416	1,003907016	1807,804134
1870	2.040.277,00	21.254	95,99302832	1,00280799	1814,867254
1880	2.156.601,00	22.403	96,26257576	1,008606856	1819,963383
1890	2.263.873,00	23.317	97,09109391	1,015810644	1835,627546
1900	2.367.028,00	24.000	98,62616667	1,139526596	1864,65
1910	2.465.514,00	21.938	112,3871399	1,101955069	1469,729799
1920	2.768.936,00	22.358	123,8455786	1,083028959	1619,576203
1930	3.239.303,00	24.151	134,1283481	1,07576645	1754,047929
1940	4.138.196,00	28.680	144,2907769	1,151376729	1886,945915
1950	6.134.454,00	36.925	166,1330428	1,422055636	2172,585615
1951	8.637.823,00	36.562	236,2504297	0,9709737837	3089,537619
1952	9.250.433,00	40.326	229,3929737	1,000466015	2999,860032
1953	9.717.926,00	42.344	229,4998742	1,01518644	3001,258011
1954	10.164.850,00	43.629	232,9851602	1,011799624	3046,836435
1955	10.553.514,00	44.769	235,7342975	1,016594593	3082,787959

1956	11.047.097,00	46.098	239,6462122	1,009986746	3133,94557
1957	11.578.174,00	47.836	242,039498	1,009571484	3165,243488
1958	12.270.523,00	50.216	244,3561751	1,006626056	3195,539565
1959	12.992.217,00	52.819	245,9752927	0,8174434762	3216,713388
1960	11.190.573,00	55.655	201,0708984	1,242866655	2629,481374
1961	14.606.323,00	58.448	249,9043148	1,018684066	3268,094719
1962	15.571.158,00	61.166	254,5735437	1,019066704	3329,156018
1963	16.594.785,00	63.967	259,427422	1,018717636	3392,63205
1964	17.641.232,00	66.751	264,2832901	1,020649547	3456,134101
1965	18.871.346,00	69.961	269,7406204	1,019935852	3527,501706
1966	20.285.141,00	73.732	275,1181294	1,020651983	3597,825457
1967	21.950.977,00	78.173	280,7998643	1,018211078	3672,127687
1968	23.773.787,00	83.150	285,9135326	1,02735115	3739,001092
1969	25.636.166,00	87.277	293,7335965	0,8947039476	3841,267071
1970	23.467.178,00	89.295	262,8046083	1,223909825	3436,796812
1971	28.424.516,00	88.371	321,6491421	1,179606605	4206,329384
1972	28.976.643,00	76.371	379,4194524	1	4961,813922

Table 3. Estimated Potential Economic Activity, GDP per capita, and Velkskala Population for the Western Sahara, 10000BC-1972AD, * = >8x Outliers Removed.

Conclusion.

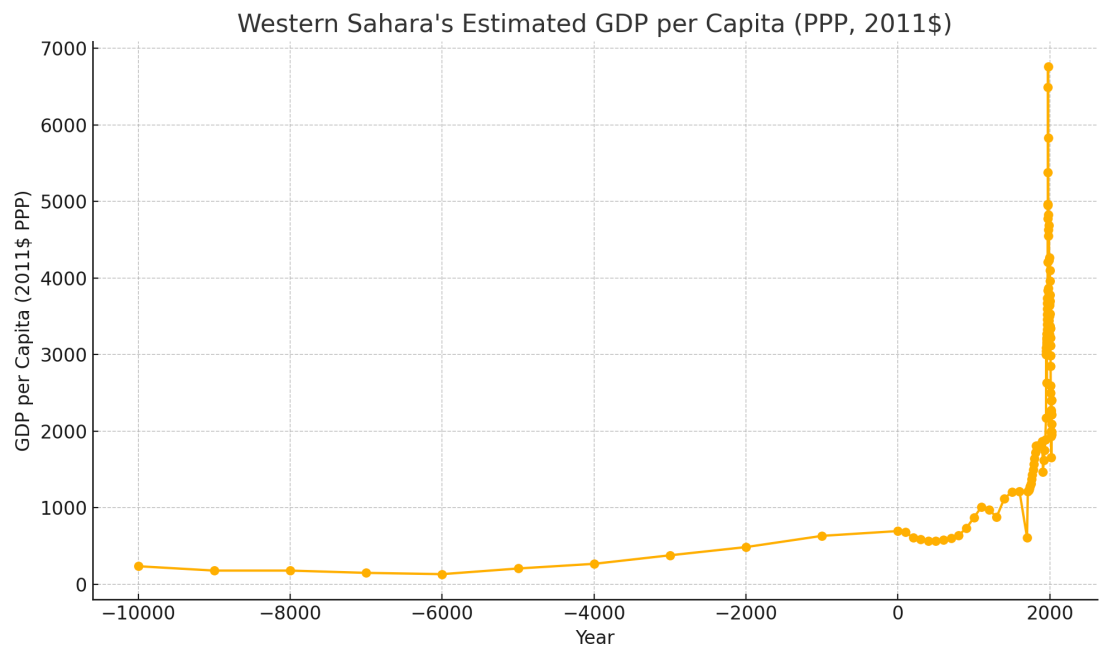


Figure 2. Western Sahara’s estimated GDP per capita (PPP, 2011\$).

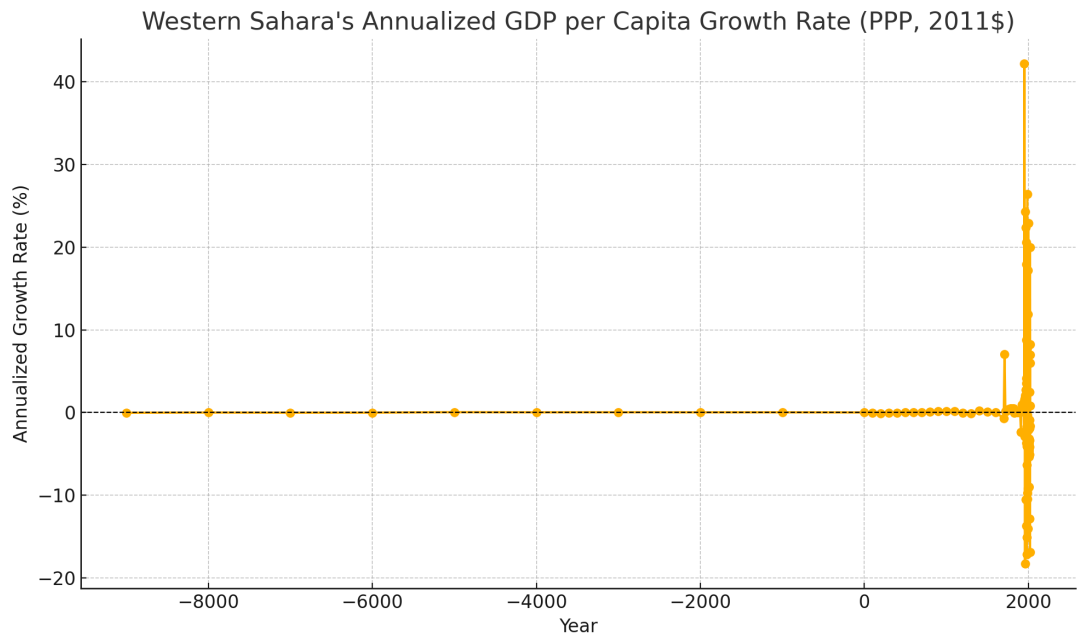


Figure 3. Estimated annualised GDP per capita (PPP, 2011\$) growth.

Given the relatively large resultant dataset for the Western Sahara, we feel that it is necessary to publish it in appendix form; and some year/value cleaning within the .csv is still necessary although relatively easy to do due to overlapping time series.

The previous paper in this series on filling in missing data had to do with European microstates, and given that Gapminder has filled in 23 missing countries on the Maddison Project Database, this lowers the remaining countries to be done to just 2/28, namely Somaliland and Kosovo - both of which are included as World Bank jurisdictions [16][17].

We plan to address these countries individually in our next paper.

Appendices.

- Appendix 1: [Error Correction - Western Sahara - 10000BC-2025AD](#)
- Appendix 2: [Eoscala/Velkscale Database and CLI - 10000BC-2025AD](#)

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Note: This is a **self-citation** to a previous paper in this series on filling in missing entries in the MPD.

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Note: This is a **self-citation** to our previous work regarding gridmapping/HYDE-SEDAC OLS models.